

CLAIMS

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1. A flash memory device, characterized by:
a silicon substrate,
a first electrode formed on said silicon
substrate with an insulation film interposed
therebetween, and
10 a second electrode formed on said first
electrode with an inter-electrode insulation film
interposed therebetween,
said inter-electrode insulation film having
15 a stacked structure including at least one silicon
oxide film and one silicon nitride film, at least a
part of said silicon oxide film containing Kr with a
surface density of 10^{10} cm^{-2} or more.

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2. A flash memory device as claimed in
claim 1, characterized in that said first electrode
25 includes a polysilicon film on a surface thereof, and
wherein said inter-electrode insulation film has a
stacked structure in which a first silicon nitride
film, a first silicon oxide film, a second silicon
nitride film and a second silicon oxide film are
30 stacked consecutively.

3. A flash memory device as claimed in
claim 1, characterized in that said first electrode
includes a polysilicon film on a surface thereof, and
wherein said inter-electrode insulation film is
5 formed of three layers of a silicon oxide film, a
silicon nitride film and a silicon oxide film.

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4. A flash memory device as claimed in
claim 1, characterized in that said first electrode
includes a polysilicon film on a surface thereof, and
wherein said inter-electrode film is formed of two
15 layers of a first silicon nitride film and a second
silicon oxide film.

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5. A method of fabricating a flash memory
device, said flash memory device comprising a silicon
substrate, a first electrode formed on said silicon
substrate with an insulation film interposed
25 therebetween, and a second electrode formed on said
first electrode with an inter-electrode insulation
film interposed therebetween, said inter-electrode
insulation film having a stacked structure including
therein at least one silicon oxide film and one
30 silicon nitride film,

characterized in that said silicon oxide
film is formed by a process comprising the steps of:
supplying a gas containing oxygen and a gas

predominantly of Kr into a processing chamber, and exciting plasma in said processing chamber by a microwave.

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6. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,

10 characterized in that said first and second silicon oxide films are formed by a process comprising the steps of: introducing a gas containing oxygen and a gas predominantly of Kr into a processing chamber, and exciting plasma in said

15 processing chamber by a microwave.

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30 7. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed

therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a 5 first silicon oxide film, a silicon nitride film and a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface, characterized in that said first and second silicon oxide films are formed by a process 10 comprising the steps of: introducing a gas containing oxygen and a gas predominantly of Kr into a processing chamber, and exciting plasma in said processing chamber by a microwave.

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8. A method of fabricating a flash memory device, said flash memory device comprising a silicon 20 substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a two-layer structure in which a silicon oxide film and a silicon nitride film are stacked consecutively, said first electrode having a polysilicon surface, 25 characterized in that said silicon oxide film are formed by a process comprising the steps of: introducing a gas containing oxygen and a gas predominantly of Kr into a processing chamber, and exciting plasma in said processing chamber by a 30

microwave.

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9. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure including at least one silicon oxide film and at least one silicon nitride film,

characterized in that said silicon oxide film is formed by a process comprising the step of: exposing a silicon oxide film deposited by a CVD process to atomic state oxygen O^* formed by microwave excitation of plasma in a mixed gas of an oxygen-containing gas and an inert gas predominantly of a Kr gas.

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10. A fabrication process of a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode

insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second silicon oxide film are stacked consecutively, said 5 first electrode having a polysilicon surface,

characterized in that said first and second silicon oxide films are formed by a process comprising the step of: exposing a silicon oxide film deposited by a CVD process to atomic state oxygen O* 10 formed by exciting plasma in a mixed gas of a gas containing oxygen and a gas predominantly of a Kr gas, by a microwave.

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11. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon 20 substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a first silicon oxide film, a silicon nitride film and 25 a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said second silicon oxide film are formed by a process comprising the 30 step of: exposing a silicon oxide film deposited by a CVD process to atomic state oxygen O* formed by exciting plasma in a mixed gas of a gas containing oxygen and a gas predominantly of a Kr gas by a

microwave.

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12. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure including at least one silicon oxide film and at least one silicon nitride film,

characterized in that said silicon nitride film are formed by a process comprising the steps of: introducing a gas containing any of an NH₃ gas or an N₂ gas and an H₂ gas and a gas predominantly of an Ar 20 gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

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13. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode

insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second silicon oxide film are stacked consecutively, said 5 first electrode having a polysilicon surface,

characterized in that said first and second silicon nitride films are formed by a process comprising the steps of: introducing an NH_3 gas or a gas containing N_2 and H_2 and a gas predominantly of 10 an Ar gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

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14. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon 20 substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a first silicon oxide film, a silicon nitride film and 25 a second silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said silicon oxide film are formed by a process comprising the steps of: 30 introducing an NH_3 gas or a gas containing N_2 and H_2 and a gas predominantly of an Ar gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

15. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a two-layer structure in which a silicon oxide film and a silicon nitride film are stacked consecutively, said first electrode having a polysilicon surface,

characterized in that said silicon nitride film are formed by a process comprising the steps of: introducing an NH₃ gas or a gas containing N₂ and H₂ 15 and a gas predominantly of an Ar gas or a Kr gas into a processing chamber, and exciting plasma in said processing chamber by a microwave.

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16. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure containing 25 at least one silicon oxide film and at least one silicon nitride film,

characterized in that said silicon nitride film is formed by a process comprising the step of:

exposing a silicon nitride film deposited by a CVD process to hydrogen nitride radicals NH^* formed by microwave excitation of plasma in a mixed gas of an NH_3 gas or a gas containing N_2 and H_2 and a gas 5 predominantly of an Ar gas or a Kr gas.

10 17. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said 15 first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a stacked structure in which a first silicon nitride film, a first silicon oxide film, a second silicon nitride film and a second 20 silicon oxide film are stacked consecutively, said first electrode having a polysilicon surface, characterized in that each of said first and second silicon nitride films is formed by a process comprising the step of: exposing a silicon 25 nitride film deposited by a CVD process to hydrogen nitride radicals NH^* formed by exciting plasma in a mixed gas of an NH_3 gas or a gas containing N_2 and H_2 and a gas predominantly of an Ar gas or a Kr gas by a microwave.

18. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said first electrode having a polysilicon surface,
5 characterized in that said silicon nitride film is formed by a process comprising the step of: exposing a silicon nitride film deposited by a CVD process to hydrogen nitride radicals NH* formed by exciting plasma in a mixed gas of an NH₃ gas or a gas containing N₂ and H₂ and a gas predominantly of an Ar 10 gas or a Kr gas by a microwave.
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20 19. A method of fabricating a flash memory device, said flash memory device comprising a silicon substrate, a first electrode formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-electrode insulation film interposed therebetween, said inter-electrode insulation film having a two-layer structure in which a silicon oxide film and a silicon nitride film are stacked consecutively, said first electrode having a 25 polysilicon surface,
30 characterized in that said inter-electrode insulation film is formed by a process comprising the step of: exposing a silicon nitride film deposited by

a CVD process to hydrogen nitride radicals NH^* formed by exciting plasma in a mixed gas of an NH_3 gas or a gas containing N_2 and H_2 and a gas predominantly of an Ar gas or a Kr gas by a microwave.

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20. A method of fabricating a flash memory
10 device, said flash memory device comprising a silicon substrate, a first electrode of polysilicon formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode formed on said first electrode with an inter-
15 electrode oxide film interposed therebetween,
characterized in that said inter-electrode oxide film is formed by a process comprising the steps of:

depositing a polysilicon film on said
20 silicon substrate as said first electrode; and
exposing a surface of said polysilicon film to atomic state oxygen O^* formed by exciting plasma in a mixed gas of a gas containing oxygen and an inert gas predominantly of a Kr gas by a microwave.

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21. A method of fabricating a flash memory
30 device, said flash memory device comprising a silicon substrate, a first electrode of polysilicon formed on said silicon substrate with an insulation film interposed therebetween, and a second electrode

formed on said first electrode with an inter-electrode nitride film,

characterized in that
said inter-electrode nitride film is formed by a
5 process comprising the steps of:

depositing a polysilicon film on said
silicon substrate as said first electrode; and

10 exposing a surface of said polysilicon film
to hydrogen nitride radicals NH* formed by exciting
plasma in a mixed gas of a gas containing nitrogen
and hydrogen and an inert gas predominantly of a Kr
gas by a microwave.

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22. A method of fabricating a flash memory
device, said flash memory device comprising a silicon
substrate, a first electrode of polysilicon formed on
20 said silicon substrate with an insulation film
interposed therebetween, and a second electrode
formed on said first electrode with an inter-
electrode oxynitride film interposed therebetween,

characterized in that said inter-electrode
25 oxynitride film being formed by a process comprising
the steps of:

depositing a polysilicon film on said
silicon substrate as said first electrode; and

30 converting a surface of said polysilicon
film to a silicon oxynitride film by exposing said
polysilicon film to plasma formed by exciting a mixed
gas of an inert gas predominantly of Ar or Kr and a
gas containing oxygen and nitrogen by a microwave.

23. A method of forming a silicon oxide film, characterized by the steps of:

depositing a polysilicon film on a substrate; and

5 forming a silicon oxide film on a surface of said polysilicon film by exposing the surface of said polysilicon film to atomic state oxygen O*, said atomic state oxygen O* being formed by exciting plasma in a mixed gas of a gas containing oxygen and 10 an inert gas predominantly of a Kr gas by a microwave.

15 24. A method of forming a silicon oxide film as claimed in claim 23, characterized in that said mixed gas is a mixture of oxygen and an inert gas predominantly of a Kr gas with a mixing ratio of 3% for oxygen and 97% for the inert gas.

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25 25. A method of forming a silicon oxide film as claimed in claim 23, characterized in that said plasma has an electron density of 10^{12} cm^{-3} or more on said surface of said polysilicon film.

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26. A method of forming a silicon oxide film as claimed in claim 23, characterized in that

said plasma has a plasma potential of 10 V or less at said surface of said polysilicon film.

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27. A method of forming a silicon nitride film, characterized by the steps of:

10 depositing a polysilicon film on a substrate; and
15 forming a nitride film on a surface of said polysilicon film by exposing the surface of said polysilicon film to hydrogen nitride radicals NH^* , said hydrogen nitride radicals NH^* being formed by plasma that is excited in a mixed gas of a gas containing nitrogen and hydrogen as constituent elements and an inert gas predominantly of an Ar gas or a Kr gas by a microwave.

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28. A method of forming a silicon nitride film as claimed in claim 27, characterized in that
25 said gas containing nitrogen and hydrogen is an NH_3 gas.

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29. A method of forming a silicon nitride film as claimed in claim 27, characterized in that said mixed gas is a mixture of an NH_3 gas and an

inert gas predominantly of an Ar gas or a Kr gas with a mixing ration of 2% for said NH₃ gas and 98% for said inert gas.

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10 30. A method of forming a silicon nitride film as claimed in claim 27, characterized in that said gas containing nitrogen and hydrogen is a mixed gas of an N₂ gas and an H₂ gas.

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31. A method of forming a silicon nitride film as claimed in claim 27, characterized in that said plasma has an electron density of 10¹²cm⁻³ or more at said surface of said polysilicon film.

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25 32. A method of forming a silicon nitride film as claimed in claim 27, characterized in that said plasma has a plasma potential of 10 V or less at said surface of said polysilicon film.

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33. A method of forming an oxynitride film, characterized by the steps of:

depositing a polysilicon film on a substrate; and

5 converting a surface of said polysilicon film to a silicon oxynitride film by exposing said polysilicon film to plasma formed by exciting a mixed gas of an inert gas predominantly of Ar or Kr and a gas containing oxygen as a constituent element and a gas containing nitrogen as a constituent element, by a microwave.

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34. A method of forming a silicon
15 oxynitride film as claimed in claim 33, characterized in that said gas containing nitrogen is an NH₃ gas.

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35. A method of forming a silicon oxynitride film as claimed in claim 33, characterized in that said mixed gas is a mixture of an inert gas predominantly of Ar or Kr and an oxygen gas and an
25 NH₃ gas with a mixing ratio of 96.5% for said inert gas and 3% for said oxygen gas and 0.5% for said NH₃ gas.

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36. A method of forming a silicon oxynitride film as claimed in claim 33, characterized

in that said gas containing nitrogen is a mixed gas of an N₂ gas and an H₂ gas.

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37. A method of forming a silicon oxynitride film as claimed in claim 33, characterized in that said plasma has an electron density of 10¹² cm⁻³ or more at said surface of said polysilicon film.

15 38. A method of forming a silicon oxynitride film as claimed in claim 33, characterized in that said plasma has a plasma potential of 10V or less at said surface of said polysilicon film.

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39. A method of forming a silicon oxide film on a polysilicon film, characterized by the 25 steps of:

forming plasma containing therein atomic state oxygen O* in a processing vessel of a microwave processing apparatus, said microwave processing apparatus including, in addition to said processing vessel, a shower plate provided in a part of said processing vessel so as to extend parallel with a substrate to be processed, said shower plate including a number of apertures for supplying a

plasma gas toward said substrate to be processed, and
a microwave radiation antenna provided such that said
microwave radiation antenna emits a microwave into
said processing vessel through said shower plate,
5 said plasma being formed by supplying an inert gas
predominantly of Kr and a gas containing oxygen into
said processing vessel via said shower plate, and by
supplying a microwave into said processing vessel
from said microwave radiation antenna through said
10 shower plate; and

oxidizing, in said processing vessel, a
surface of said polysilicon film formed on said
substrate by said plasma, to form said silicon oxide
film.

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40. A method of forming a silicon oxide
20 film as claimed in claim 39, characterized in that
said plasma has an electron density of 10^{12}cm^{-3} or
more at said surface of said polysilicon film.

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41. A method of forming a silicon oxide
film as claimed in claim 39, characterized in that
said plasma has a plasma potential of 10V or less at
30 said surface of said polysilicon film.

42. A method of forming a silicon nitride film on a polysilicon film, characterized by the steps of:

forming plasma containing therein hydrogen
5 nitride radicals NH* in a processing vessel of a microwave processing apparatus, said microwave processing apparatus including, in addition to said processing vessel, a shower plate provided in a part of said processing vessel so as to extend parallel
10 with a substrate to be processed, said shower place including a number of apertures for supplying a plasma gas toward said substrate to be processed, and a microwave radiation antenna provided such that said microwave radiation antenna emits a microwave into
15 said processing vessel through said shower plate, said plasma being formed by supplying an inert gas predominantly of Ar or Kr and a gas containing nitrogen and hydrogen into said processing vessel via said shower plate, and by supplying a microwave into
20 said processing vessel from said microwave radiation antenna through said shower plate; and
nitriding, in said processing vessel, a surface of said polysilicon film formed on said substrate by said plasma, to form said silicon
25 nitride film.

30 43. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said gas containing nitrogen and hydrogen is an NH₃ gas.

44. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said gas containing nitrogen and hydrogen is a mixed 5 gas of an N_2 gas and an H_2 gas.

10 45. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said plasma has an electron density of 10^{12} cm^{-3} or more at said surface of said polysilicon film.

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20 46. A method of forming a silicon nitride film as claimed in claim 42, characterized in that said plasma has a plasma potential of 10V or less at said surface of said polysilicon film.

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47. A method of forming a silicon oxynitride film on a polysilicon film, characterized by the steps of:

30 forming plasma containing therein atomic state oxygen O^* and hydrogen nitride radicals NH^* in a processing vessel of a microwave processing apparatus, said microwave processing apparatus including, in addition to said processing vessel, a

shower plate provided in a part of said processing vessel so as to extend parallel with a substrate to be processed, said shower place including a number of apertures for supplying a plasma gas toward said 5 substrate to be processed, and a microwave radiation antenna provided such that said microwave radiation antenna emits a microwave into said processing vessel through said shower plate, said plasma being formed by supplying an inert gas predominantly of Ar or Kr 10 and a gas containing oxygen as a constituent element and a gas containing nitrogen as a constituent element into said processing vessel via said shower plate, and by supplying a microwave into said processing vessel from said microwave radiation 15 antenna through said shower plate; and
oxynitriding, in said processing vessel, a surface of said polysilicon film formed on said substrate by said plasma, to form said silicon oxynitride film.

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48. A method of forming a silicon
25 oxynitride film as claimed in claim 47, characterized in that said gas containing nitrogen and hydrogen is an NH₃ gas.

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49. A method of forming a silicon

oxynitride film as claimed in claim 47, characterized in that said gas containing nitrogen and hydrogen is a mixed gas of an N₂ gas and an H₂ gas.

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50. A method of forming a silicon oxynitride film as claimed in claim 47, characterized 10 in that said plasma has an electron density of 10¹²cm⁻³ or more at said surface of said polysilicon film.

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51. A method of forming a silicon oxynitride film as claimed in claim 42, characterized in that said plasma has a plasma potential of 10V or less at said surface of said polysilicon film.

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